Before the
Federal Communications Commission
Washington, DC 20554

In the Matter of	)	
	)	Docket No. 02-86
AIRCELL, INC.	)	DA 03-721
	)	
Petition for Extension of Waiver	)	

To: The Commission

COMMENTS OF LUCENT TECHNOLOGIES INC.

Lucent herein responds to the Commission's request for comments on AirCell's Petition to extend its waiver of Section 22.925 of the Commission's Rules. Lucent provided technical support in the evaluation of the compatibility tests designed to assess potential interference from the AirCell system into terrestrial commercial mobile radio systems, and limits its comments to observations related to the test program.

V-COMM, LLC, a telecommunications engineering consultant, was engaged by AT&T Wireless Services, Cingular, and Verizon to conduct these independent tests of the interference potential. Lucent reviewed the test plan, provided field assistance relative to base station operations, provided software tools for data processing and analysis, and offered consultation on methods of data analysis, interference assessment, and the interpretation of system service measurements.

The Lucent comments are meant to provide added insight into the compatibility tests through discussions/observations in several areas key to the V-COMM study. These include noise floor analysis, interference margins in cell design, and levels of interference associated with performance degradation. The Lucent comments also include, as an Appendix, an analysis that offers a theoretical description of the impact of external interference on CDMA systems.

Comments on *'V-COMM's AirCell Compatibility Test'*

1.0 Introduction

The objective of this report is to present comments on the *'AirCell Compatibility Test'* performed and managed by the firm, *V-COMM, LLC.* The primary focus of the comments is on test planning, operations, data collection, data processing, and key topics discussed in the engineering report produced by V-COMM.

Our comments are based upon our role as an observer and a consultant for these tests. Specifically, Lucent provided support for several aspects of the test by offering our expertise in technical support of our equipment as well as general consultation in the field of communication systems engineering and analysis.

Lucent Technologies' support of this testing was provided for several reasons. As an equipment and service vendor provider, Lucent have always been committed to improving and monitoring developments of our field and trial systems, as well as assisting our customers in resolving any matters related to radio interference. Moreover, Lucent clearly has an interest in evaluating any issues affecting the field systems, since in some cases, the performance of a system is warranted to operate under reasonable and normal operating coniditions. Furthermore, execution of the tests entailed the use of Lucent base station equipment. Accordingly, correct and objective procedures necessitated our consultation and support for the operation of the base station as well as the use of embedded diagnostics and equipment.

Specifically, our assistance has included:

- Review and comment of the AirCell compatibility test plan
- Field assistance in support of base station operation (e.g., test scripting and setup, power measurements, channel selection)
- Provision of software tools for data processing and analysis
- Consultation on methods of data analysis (e.g., link budget), means of interference assessment, and interpretation of embedded diagnostics (i.e., service measurements)
- Test observation

Lucent did not directly participate in test procedures or data collection; nor did Lucent participate in any regulatory actions involving rebuttals and motions concerning any of the parties involved. Our comments herein are limited to technical remarks on the methodology and results in order to further illuminate the issues involved.

The remainder of this document is organized as follows. In section 2, we provide a brief overview of Lucent Technologies's expertise within the area of wireless communication and its unique qualifications for test support. The test conducted by V-COMM is then summarized in section 3.[1] We offer remarks on test methods, analysis procedures, and results in section 4. A summary and conclusion is provided in section 5.

2.0 Historical Perspective

As a company, Lucent Technologies (previously part of AT&T) has been involved in the development and production of communications equipment since the virtual dawn of the telecommunication industry. Our corporate history spans landline telegraphs, wire line telephone systems, and wireless voice and data technology. We have dedicated our products and services to the highest degree of quality. The perseverance and breadth of our technical staff, which includes leading scientists and engineers from our research arm, Bell Laboratories, is unmatched.

Within the area of wireless communications, Lucent has developed industry-standard equipment that employs AMPS, TDMA, and CDMA technology. Today, much of our equipment is used in the field as an integral part of many cellular and PCS wireless voice and data applications. Our major domestic customers include AT&T Wireless, Cingular, Verizon Wireless, and Sprint PCS. In addition, a significant number of international customers (e.g., China Unicom and Reliance India) deploy our equipment. Lucent has developed leading-edge wireless base station equipment and have been instrumental in engineering the current industry transition to third generation (3G) services. As a vendor that offers multiple radio technologies, Lucent has developed considerable expertise in the observation, analysis, and mitigation of mutual interference effects.

Our qualifications uniquely positioned us to support the AirCell Compatibility Test. The test was conducted using Lucent base stations. In addition, Lucent embedded hardware and software tools were used to analyze the performance impact of observed interference. Lucent's status as the equipment and tool vendor allowed us to provide key support in ensuring that the operation of Lucent equipment within the test was accurate and objective. Moreover, Lucent's expertise within the area of mutual interference analysis allowed it to provide significant insights into test procedures and data analysis.

Some of these insights are discussed in section 4, below; however, for convenience, we first overview the compatibility test procedure.

3.0 Overview of Tests

AirCell channels operate on analog channels in licensed spectrum; however, the large cell radius of the AirCell network can result in conditions where the AirCell link is using channels that violate the channel reuse constraints of the cellular network below the airplane. For example, an analog channel obtained from the local cellular operator at the

[1] For more information regarding the AirCell compatibly tests, please refer to V-COMM test plans.

call origination point may be used over a distance of approximately 100 miles before handoff to the next AirCell base station. Within this distance, the airplane may well fly over areas where the channel assigned to the AirCell call at its point of origination is being reused by the underlying cellular terrestrial network in accordance with its reuse plan. The AirCell call is thus a potential source of co-channel interference to the ground network. AirCell offers a number of features designed to mitigate this issue, including the use of horizontally polarized signals and power control that reduces airplane transmitter power near its serving site.

The following summarizes the analysis on the effects of co-channel interference from AirCell. The AirCell Compatibility test can be organized under two phases. In phase 1, the interference levels at several terrestrial base stations from an in-flight AirCell call were recorded and characterized. In phase 2, interference levels consistent with these observations were injected into a base station in order to quantify any degradation within the terrestrial network performance. Phase 2 was conducted for three radio technologies, AMPS, TDMA, and CDMA.

The purpose of phase 1 was to measure AirCell mobile transmit power received at typical cell site locations. These measurable levels of AirCell signal can be received as interference power at any normal terrestrial cell sites near the aircraft flight paths. V-COMM had chosen three sites to conduct these measurements, Marlboro - a collocated terrestrial and AirCell site along a test flight path, Swainton - a terrestrial site located at the end point of the test flight path, and Oak Hill - a terrestrial site located approximately 30 miles parallel to the test flight path. These straight-line flight paths tests contributed to insights on typical AirCell transmit power measurements under normal everyday operations. AirCell mobiles were operating with dynamic power control limited to a maximum ERP of 44.8 dBm (30mW). Another set of circular flight paths were conducted in order to gain insight on receive power on various types of antennas, i.e., vertical, slant-polarized, and omni as it relates to AirCell's horizontally polarized antennas. All of the tests described were performed at various altitudes ranging from 2000 ft (AMSL) to 35000 ft. The circular path tests were flown concentrically around the Marlboro site ranging from radii of 2 miles up to 80 miles from the serving site.

The purpose of phase 2 was to characterize the resulting effect from interference signals by injecting AirCell AMPS-like narrow-band interference levels into AMPS, TDMA, and CDMA base stations that operate under normal loaded system operations. Specific performance degradation in phase 2 was assessed by comparing the drive test performance of a terrestrial call before ("baseline") and after ("measurement") the injection of interference into the base station. The baseline and measurement were conducted along identical drive routes within a normal background of live traffic.[2] The effects examined were blocked/dropped calls at the mobile, base station transmit power, C/I or Eb/No degradation, MOU usage, MOS scores, and other significant performance indicators.

[2] These tests performed during weekdays between 9 am and 3 pm.

A significant aspect of these tests was to run the above procedures under normal operation to examine the effects of interference. This strategy would indicate in a nominal operations scenario whether any harmful effects arose from the AirCell interference.

3.1 Test plan and test audits

A test plan was developed by V-COMM to outline the procedures, objectives, and configurations for these tests. Lucent took part in the review of the test plan in order to ensure its ability to measure typical AirCell interference levels, and to measure the impact on performance under a controlled experiment with characteristics of normal systems operations with interference.

To further enforce the integrity of the tests performed; Lucent randomly audited the tests on site. Lucent has visited onsite test during phase 1 flight tests and during the AMPS, TDMA, and CDMA phase 2 tests. Lucent verified the specific test procedure runs, and the data collected. Each test process was considered a success only when all aspects of the test including configuration, procedure, and data collected were valid. For example, during one run of CDMA tests to measure dropped calls, special care was taken to ensure typical loading of the system was set up as baseline case, and that all instance of injected interference was measured. Audits also included validation that the same drive test routes were used in phase 2 tests.

3.2 Support

Lucent provided support of base station equipment set up and cooperated in disseminating detailed general knowledge of field and special test operations. For example, special data entry was necessary to setup a TDMA operating channel using Lucent's private system ID for these tests. In some of the CDMA load testing experiments, a Lucent O. C. N. S. (Orthogonal Channel Noise Simulator) load was setup and used.

Lucent also helped the V-COMM engineers conduct specific measurements. For example, during AMPS noise floor testing, Lucent provided information regarding base station typical operating performance parameters such as noise figure, and in-lab measured receiver noise bandwidth. This data helped verify the noise floor measurements performed by V-COMM on a Lucent AMPS base station.

In addition, many of Lucent's performance metric processing tools were used. V-COMM processed the power level measurements (PLM) with Lucent's Autopace software. Lucent call trace software was used to process many of the other measurements such as E_b/N_o, transmit power, RSSI measurements, etc. At the same time, third party hardware and software test equipment were used to collect mobile performance status, i.e., blocked and dropped calls.

Lucent also suggested a means of processing data that was consistent with the sample sizes demanded by test logistics (i.e., the need to characterize a number of metrics at a large number of injected interference levels). For example, Lucent suggested the need to fit trend lines to the data. This process, coupled with the physical knowledge that performance degradation must monotonically increase with interference levels, increases the statistical significance of the results.

The trending is less significant for metrics that inherently contain larger sample sizes; for example, data sets collected via PLM or Lucent call trace (i.e., RSSI power, PLM measurements, C/I or E_b/N_o measurements, mobile transmit power, Frame Error Rate (FER) %, etc.). In this case, for each level of interference injected, the measured result is considered to be very statistically significant, with small sample variance. However, the trending of curves in these instances still adds significance to the result.

Lucent also discussed the processing of data via time averages or spatial averages. In the latter case, performance can be characterized by location along the drive routes; in the former case, performance is characterized by time along the drive route, thereby weighing the quantity of data by subscriber speed characteristics such as waiting at a traffic light. The choice of time bins for the analysis is adequate in the sense that it better captures the typical user experience (one of the major goals of the test); moreover, repeated drive tests under the same interference levels showed a small variance, thereby allowing a relative comparison between performance at different injected interference levels.

4.0 Overview of results

For completeness, we overview a selection of observed results from the field data (more information can be found in the V-COMM report.)[3]

4.1 <u>Range of received AirCell interference</u>

In the phase 1 test, the resulting interference level seen at terrestrial sites ranges from approximately –72 dBm to –130 dBm.[4] The distribution of these received levels depended on the test configuration. In general, the test showed that the highest levels were received by the horizontal, and slant-45 polarized antennas. Other antennas, which offer more isolation to the horizontally polarized AirCell transmit signals, received interference power at a lower level. This observation is not unexpected, and can be supported by calculations.

It was observed from the data sets, that the highest level of received interference arrived when the AirCell mobile is flying in the vicinity toward the terrestrial site at approximately a mile or so from its center, for a period of several seconds to a minute (depending on the velocity of the plane).

[3] See *Engineering Report on AirCell Compatibility Test*, by V-COMM, LLC.
[4] The higher levels were observed on the horizontal pole antenna, as expected.

Key results from flight path testing are:

- The range of interference levels seen at the various terrestrial sites using vertical pole antennas are between –95 dBm and –120 dBm.[5]
- The average AirCell mobile transmitted DPC level is between 3 and 4.
- For altitudes at 5000 feet or lower, the interference level can be greater than –98 dBm at these terrestrial sites.
- For altitudes at 10000 feet or lower, the interference level can be greater than –108 dBm.
- For altitude at 20000 feet or higher, the interference level can be less than –111 dBm.
- At 2 miles and closer from terrestrial sites, the interference level can be greater than –108 dBm.
- At 5 miles and closer from the terrestrial sites, the interference level can be greater than –110 dBm.
- At 10 miles and closer from the terrestrial sites, the interference level can be greater than –118 dBm.

4.2 Noise floor analysis

V-COMM had measured the actual noise floor for a set of typical Lucent AMPS base stations. The range of these measurement ranged from –123 to –127 dBm/30 kHz. Typically, the specified (warranted) noise floor is –124 dBm/30 kHz. Although the measurements were within reasonable range of the specified value, Lucent provided additional measurements of the base-band channel filter, and a noise figure measurement for a typical AMPS base station. These measurements were used to show that normally the Lucent AMPS base station in fact exceeds the –124 dBm noise floor specification. Moreover, although many of the field AMPS sites operate with better noise floor than specified, any Lucent analyses performed were based on the specification of –124 dBm noise floor value.

4.3 Toll quality and cell design margin

Typical target operation for AMPS and TDMA is to achieve C/I_{total} (I_{total} represents the sum of co-channel interference and receiver noise, $I_{co} + I_o$) of approximately 16 to 18 dB. From the baseline measured scenarios, it was observed that the cell under test can achieve C/I_{total} much higher than the minimum specified 16 dB, therefore indicating that the drive routes chosen for test operate with some amount of design margin. This choice is consistent with the objective of testing normal operation for typical cells, which may well have additional design margin in their operating systems; moreover, it skews the results in AirCell's favor as proportionately more interference is required to degrade

[5] Some equipment did not register measurement readings below –120 dBm. It is likely that these reading indicate interference levels below –120 dBm.

performance. In fact, at some points C/I_{total} values up to 40 dB for the TDMA cell was observed. As C/I_{total} degrades below its specified design level, the link degrades, and performance impacts occur.

4.4 Discussion: Interference impact level on various performance metrics

V-COMM's conclusions are contained in its report, which uses trend-line analysis and a hypothetical flight path case study to quantify the interference effects. Further discussion on the flight path analysis is contained in section 4.5 (see below). In this section, we attempt to add additional insight into test results by analyzing the field data in an alternative manner.

In this process, we look directly at interference effects that meet a certain level of statistical significance determined solely by the sample size. Performance degradation is examined via standard metrics such as blocked call rate, dropped call rate, and channel error rate.

As previously described, the potential impact of AirCell interference on terrestrial base stations was assessed via drive test in the vicinity of a base station. Performance was measured before ("baseline") and after ("test") the injection of interference at the base station. The injected interference levels were derived from earlier measurements of AirCell flights. AMPS, TDMA, and CDMA effects were measured.

Time constraints and other logistics limited the experimental design in ways that are reflected in the data analysis. For example, in assessing blocking a single baseline trial with a modest number of call attempts was executed. Similarly, a modest number of call attempts were made at each interference level in order to be able to efficiently characterize a large number of levels. In viewing the statistical significance of results purely from sample size alone, any modest increases in blocking between baseline and test must be interpreted as statistical variability. Accordingly, a large jump in rate must be observed to declare statistically significant performance degradation with high (e.g., 95%) confidence. Moreover, the cell and drive route chosen contain design margin, thereby requiring a larger amount of interference to degrade performance (see section 4.3). These circumstances bias the data analysis in AirCell's favor, since larger levels of interference are required in order to declare performance degradation with confidence.

The lowest levels of interference that can cause statistically significant performance degradation are best observed from the TDMA tests. Values of interference in the vicinity of –117 dBm to –114 dBm caused degradation in blocked call rate. Note that these values are approximately 7 to 10 dB above the AMPS noise floor. Some performance degradation occurred at lower interference values but given this analysis method, this degradation cannot be declared statistically significant. In contrast, the degradation for –117 dBm to –114 dBm occurred with 95% confidence.

Some insight into the frequency of occurrence of interference at levels of –117 dBm to –114 dBm can be obtained by examining the recorded interference data from AirCell calls.

For example, data shows that levels above –117 dBm can be produced by an AirCell call within a 10-15 mile radius of the cell site, at an altitude of approximately one mile. For general operation within a 5-mile radius, levels are approximately –106 dBm. For AirCell mobiles that fly in the vicinity of the main beam-width of a terrestrial site, the interference can be –95 dBm or greater. In each of these cases, the AirCell mobile must be transmitting on a channel that is co-channel to the cell site in question in order for the interference levels to occur.

4.5 Case study of typical flight

The data gathered during tests of the kind described above can show the level of interference required to impact performance; however, this information alone does not add insight into the performance impact of existing systems. For example, in order to state whether the AirCell mobile would interfere with a cell it flies over, a number of considerations must be addressed. These include the distance (path loss) from the aircraft to its serving AirCell site (which dictates the level of transmit power), the altitude (path loss) between the aircraft and the cell site receiver (which determines the level of interference received), the types of antennas used at the cell site (see section 4.6), the probability that the AirCell channel being used is co-channel to an active channel at the cell site, and the probability that the AirCell mobile is active (i.e., a call is in progress). The probability that multiple aircraft employing AirCell mobiles are within interference distance of the cell site must also be considered. Lastly, the threshold for system degradation (i.e., the number of cells affected, and the duration of the effect) must also be considered.

Considerable insight into the interplay of these factors can be obtained by examining the impact of a hypothetical flight over a known flight path employing a single active AirCell mobile. In this case, the specific number and technology of existing cell sites in proximity to the flight path can be concretely identified; moreover, the typical altitude of the aircraft and distance (path loss) to proximate cell sites can be used in identifying whether received interference levels at the cell sites exceed some threshold. Finally, the AirCell mobile transmit power can be varied as a function of distance (path loss) from the AirCell serving sites along the flight path. Such an analysis can yield the number of cell sites affected.

In order to illustrate possible interference effects, V-COMM used an approach similar to that described above. Specifically, V-COMM developed two hypothetical scenarios of typical flight paths along the northeast corridor considering an AirCell mobile flying between Teterboro, NJ and Washington Dulles. The scenario examined resembles that of typical flights of either a jet flying at high altitudes and a twin-engine propeller aircraft flying at lower altitudes. A value of –114 dBm interference level was chosen as the threshold for performance degradation. The study drew conclusions about the number of cell sites that could be affected.[6]

[6] Further information can be found in the V-COMM reports.

4.6 Isolation analysis

The V-COMM testing also considered the ability of various antenna types to reject interference from the AirCell mobile.

Phase 1 circular flight path tests were performed to measure the receptibility of various terrestrial antenna types such as slant-45 polarization, vertical polarization, and omni-directional. The methodology used consisted of comparing each sample of RSSI measurements for each of the antenna types from the test receiver. The mean and moment of the differences were calculated. These values directly relate to the isolation referenced to a horizontal polarized antenna, which is what AirCell signals use.

Normal terrestrial operating systems today most often use antennas that are vertical polarized, slant-45 polarized, or omni-directional. In fact, AirCell's use of horizontally polarized antennas provides some level of interference protection to the terrestrial systems, simply based on the orthogonal isolation nature of the transmitted wave patterns. The tests show that the greatest isolation is between a horizontal pole and vertical pole antenna with isolation of about 12 to 15 dB. This is expected, since horizontal and vertical poles are, in theory, completely orthogonal. The least amount of isolation was between the horizontal and slant-45 pole antennas, as only 3 to 4 dB of isolation is achieved.

4.7 Reverse link Capacity and coverage effects on CDMA

Regardless of the source or nature of interfering signals, the clearance of spectrum remains a critical factor in achieving system performance. Co-channel interference, in this case the potential in-band interfering source from planes outfitted with AirCell mobiles, is a clear source of performance degradation, and prevents full utilization of the spectrum for its intended use. Lucent has authored a white paper concerning the effect on capacity and coverage on CDMA systems, which represent a significant portion of North American cellular systems. The analytical method assumes the interference affects a large portion of the operating system. For completeness, the paper is attached in *Appendix A*. In this section, we provide a qualitative overview of interference effects.

The current deployment of IS-95 and future third generation (3G) technology will bring increasing use of spread spectrum (i.e., CDMA) technology. Although spread spectrum systems provide inherent protection from internally generated system noise, they are susceptible to degradation caused by noise from external sources. Accordingly, an understanding of the impact of external interference on CDMA systems is beneficial.

Spread spectrum systems use complex signal processing to permit the use of multiple users in the same frequency space. For any given user the processing identifies and extracts the signal containing the desired conversation and represents signals from all other conversations as noise. The signal processing further minimizes this residual noise contributed by the multiple users, increasing the desired signal to noise ratio for a given conversation. This permits an increase in the total number of users up to the level where the signal to noise ratio is degraded such that call quality is adversely impacted.

The presence of additional sources of noise, such as that caused by out of band energy from interferers in adjacent spectrum, necessarily degrades the signal to noise ratio and impacts the call quality of the victim system. Absent the ability to control the level of such interference within the interfering system, resolution may require action within the victim system, such as a reduction in noise power generated by multiple system users. The effect of external interference may, therefore, result in the need to reduce system capacity. For higher levels of external interference, system capacity may effectively be severely degrade out and system performance significantly affected. Alternatively, if it is necessary to maintain capacity, the presence of external noise could be accommodated through a reduction in cell coverage. In such case, coverage holes within the system's footprint exist in the presence of interference. This is true for systems that are designed to specific link budget loads and performance goals. Within these coverage holes, calls may be dropped, calls be not be established, or quality of a voice call may be reduced. Effectively, the coverage holes are areas that do not meet specific designed performance goals for a wireless system.

Lucent has investigated the impact of external noise on CDMA systems, specifically by examining the effect on reverse link coverage and capacity. The Lucent study (attached as *Appendix A*) explains that call quality at the base station receiver is ideally a function of the propagation path loss, the base station receiver noise floor, and the loading factor (or number of active subscribers). The Lucent study also notes that the maximum allowable path loss dictates cell size or coverage and, therefore, that maintenance of a given level of call quality can require a trade off between cell coverage and capacity (loading). Specifically, to maintain call quality when there is an increase in base station receiver noise caused by external interference, it is necessary to reduce the maximum allowable loss and the associated cell coverage, or reduce the loading (number of subscribers) supported by the system. Practically, if it is desired to maintain system capacity, a reduction in cell size is necessary. Similarly, a desire to retain a given cell size will require a reduction in system capacity.

Although a quantitative assessment of the impact of external noise is subject to specific scenarios and system values (e.g., propagation slope, receiver noise figure and sensitivity}, the study offers examples based upon given assumptions that indicate the impact could be significant. The study suggests that if system capacity is to remain constant, the effect of an external noise power of –109 dBm – equal to the assumed receiver noise floor of –109 dBm – will demand a 30% cell coverage reduction. A second example shows that if the strategy is to maintain cell size, external noise equal to the receiver noise floor of –109 dBm demands a capacity loss of 82%.

The effects of interference on other technologies (e.g., UMTS, CDMA-2000, EVDO) are dependent on the specific channel codings used; however, the impact of interference is qualitatively similar. Performance degradation increases with the level of co-channel interference. In addition, it should be noted that even if the relative degradation in capacity is similar, the absolute number of users impacted rises because some of the newer technologies (i.e., CDMA-2000, UMTS) support a larger absolute number of voice subscribers. Per-carrier impacts may also vary as a function of bandwidth. For example, UMTS uses a carrier bandwidth that it about 3 times wider than CDMA carriers. The wider carrier raises the noise threshold higher, increasing its resistance to a narrowband interferer; however, the wider bandwidth increases the opportunity to capture more interference sources within its band.

All of the AirCell Compatibility tests were conducted outdoors; and although effects from the AirCell interference were observed, these effects may well be more pronounced for indoor systems (i.e., inside shopping malls, restaurants, etc.). Many of today's wireless providers are providing indoor operation. Under an indoor scenario, building penetration losses can hinder the uplink propagation of a cellular phone signal transmitting back to its serving cell site. Any external interference at the base station receiver (i.e., potential AirCell source from airplanes that have no penetration barriers to overcome) can therefore affect indoor systems more than outdoor systems.

5.0 Summary and Conclusion

The development of communications systems clearly requires the need to understand effects of interference, regardless of whether that interference is generated from background, thermal, man-made, broadband, or narrow-band signals. These kinds of effects are an integral part of the RF channel, and must be accounted for in performance analysis.

The effects of AirCell mobile unit interference have been examined by V-COMM and reported in their documentation.[7] Lucent provided test support through on-site audits. Lucent also assisted in providing information on the operation of its infrastructure and recommendations on data processing techniques.

In this document we have summarized some of the key observations by V-COMM, and have indicated how an alternative method of analysis shows that the minimum level of interference that can cause statistically significant degradation in a cellular (TDMA) system falls in the range of –117 dBm to –114 dBm (in a 30 kHz band). Additionally, we have discussed how analyzing the impact of a hypothetical flight on a known flight path can assess the interplay of the many factors governing system performance degradation. Such a model has been employed by V-COMM, and is described in their report.

Regardless of the source, co-channel interference can cause performance degradation and the need to have clear spectrum for its intended use remains important. We analyze the impact of interference on a CDMA system (*Appendix A*) for completeness.

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[7] See *Engineering Report on AirCell Compatibility Tests*, by V-COMM.

APPENDIX A

Lucent Technologies
Bell Labs Innovations

Subject: **Impact of External Interference on CDMA** Date: **May 24, 2002**

1. Introduction

This document discusses the impact of reverse link external (non-system) interference to a CDMA system. General coverage and capacity degradations are considered. The computations underscore the need to adequately clear spectrum of all sources of external interference in order to achieve system performance.

The definitions of *external interference* and *performance degradation* in this context must be offered with care. In network applications, the CDMA Base Station (BS) clearly receives in-band interference from other CDMA mobiles. In our discussions, we reserve the term *external interference* for in-band interference from all possible sources except the operating CDMA system. The term *performance degradation* refers to the performance impact relative to the performance achievable with clean spectrum. These definitions are further expanded, below.

Pre-commercial spectrum sweeps can determine the level of external interference present within the CDMA system. Full spectrum clearance can yield maximal capacity and coverage; however, if spectrum cannot be cleared, the presence of external interference can be compensated for *in design* through sacrifice of capacity and/or coverage. Such design solutions, although valid, are generally not considered acceptable by operators since this strategy implies that scarce, expensive radio spectrum is not being used to its full potential. For example, "noisy" spectrum can be tolerated if cells *in design* are spaced sufficiently close together; alternatively, noisy spectrum may be acceptable at full coverage if the system's design capacity is appropriately reduced.

In the following, we presume full spectrum clearance in design. *The performance degradation as a function of external interference is therefore relative to maximum coverage or maximum capacity*. The results can therefore be interpreted in two ways:

- The values can be used in design planning to trade off the ability to clear radio spectrum against the performance degradation caused by embedded interference. For example, a narrowband interferer at –115 dBm can degrade cell coverage relative to that achieved by clean spectrum by 10%. If this interferer cannot be removed, the network can still achieve full capacity provided that the design coverage is reduced by this amount. Note that, strictly speaking, this interpretation can apply only to steady-state sources of interference, since—by definition—transient sources are difficult to capture or characterize, thus making it impractical to compensate for their impact in design.

- The values can be used to project the performance impact for existing networks *originally deployed with clean spectrum* where new interference sources develop. This interpretation may be more useful for mature markets, where cell site spacing is already well established. Any performance impact on existing networks must be relative to an original (baseline) spectrum present at the time of deployment*; in this interpretation, the impact is relative to a presumed baseline clean spectrum.* Original (baseline) coverage and capacity for the network were therefore at optimal values prior to the introduction of the new interference. The degradation caused by new interference for a network deployed with a baseline spectrum that was already noisy at the time of deployment requires additional (but similar) calculations. If the interference is short-lived, these effects may be more apparent as transient sources of origination failure or dropped calls rather than constant, systematic impacts on coverage or capacity.

The rest of this memorandum is organized as follows: Section 2 addresses the relationship between the average external interference power and the CDMA reverse link coverage. Section 3 discusses the relationship between the average external interference power and the CDMA reverse link capacity. Section 4 provides a summary.

2. Effect on Reverse Link Coverage

In the typical CDMA reverse link budget for RF planning, no margin is allocated for external interference. If the cell layout is designed to the maximum allowable propagation loss dictated by the link budget analysis, the receiver noise rise caused by external interference may result in a reduction in the maximum propagation loss (used to determine the cell radius and cell coverage). In other words, when the CDMA mobile is located at the cell edge, the BS receiver quality target cannot be maintained. Since the maximum path loss in the CDMA link budget is a function of the BS receiver noise floor and loading factor, there exists a penalty tradeoff between the cell coverage and capacity.

In this section, it is assumed that the cell layout is designed to the maximum propagation loss dictated by the reverse link budget and the service objective is to maintain the capacity. In the presence of external interference from non-CDMA systems, the CDMA BS receiver noise floor rises and therefore the reverse link coverage shrinks. It is shown in A.1 that when the number of CDMA users (i.e., capacity) remains the same, the CDMA BS receiver sensitivity degradation (D) (defined as the ratio of the sensitivity ($S_{w/\ ext}$) with external interference to the sensitivity ($S_{w/o\ ext}$) without external interference) equals the noise rise caused by average external interference power, i.e.,

$$D = \frac{S_{w/\,ext}}{S_{w/o\,ext}} = \frac{I_{ext} + FN_oW}{FN_oW} \qquad (1)$$

where N_o is the spectral density of thermal noise, F is the BS receiver noise figure, I_{ext} is the average external interference power (falling into the CDMA carrier bandwidth) received by the CDMA BS antenna connector and W is the system bandwidth. If the propagation loss slope is known, then the receiver sensitivity degradation can be translated into the coverage area reduction. It follows that the CDMA reverse link cell coverage reduction ratio (R_{cov}) due to external interference can be expressed by:

$$R_{cov} = 1 - \left(\frac{L_{w/\,ext}}{L_{w/o\,ext}}\right)^{2/\gamma} = 1 - \left(\frac{S_{w/o\,ext}}{S_{w/\,ext}}\right)^{2/\gamma} = 1 - \left(\frac{FN_oW}{I_{ext} + FN_oW}\right)^{2/\gamma} \qquad (2)$$

where L denotes the maximum allowable propagation loss and γ denotes the propagation loss exponent. This equation shows that the penalty in the CDMA reverse link cell coverage (or maximum propagation loss) depends on the CDMA BS receiver noise rise as well as the propagation loss slope, and is independent of the CDMA loading.

As an example, Figure 1 shows the relationship between a CDMA reverse link coverage loss and the average external interference power when the capacity remains constant and the propagation loss slope is 35 dB/decade. It is observed that an external interference power of –105 dBm/1.23 MHz will cause about 5.5 dB noise rise and 51% cell coverage loss. As the average external interference power is -120 dBm (11 dB below the a typical receiver noise floor, -109 dBm/1.23 MHz) causing a 0.3 dB noise rise, then the cell coverage reduction becomes about 4%. Service providers can determine a tolerable reverse link external interference power level for spectrum clearance based on the elected acceptable coverage reduction when performing the network deployment study. Note that Figure 1 should be viewed as an example only and not universally applied to all products and scenarios, since the shape of the curve will differ as the noise figure and required receiver sensitivity vary.

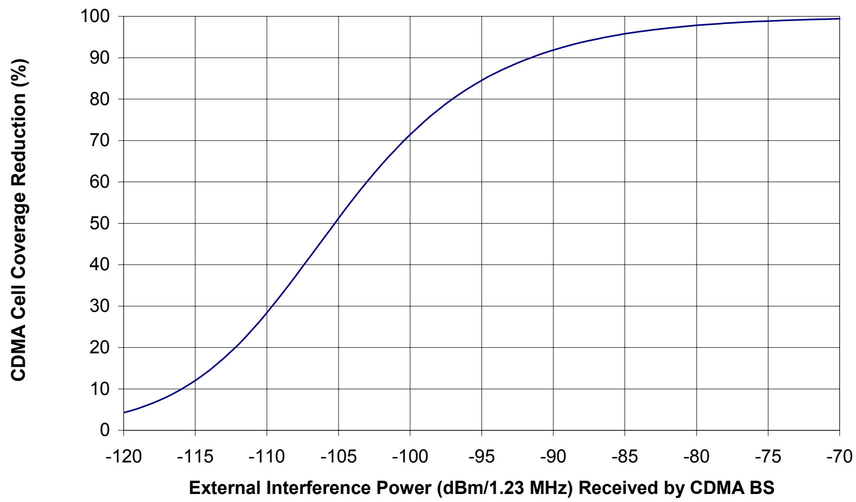


Figure 1: Effect of average external interference power on CDMA reverse link cell coverage

3. Effect on Reverse Link Capacity

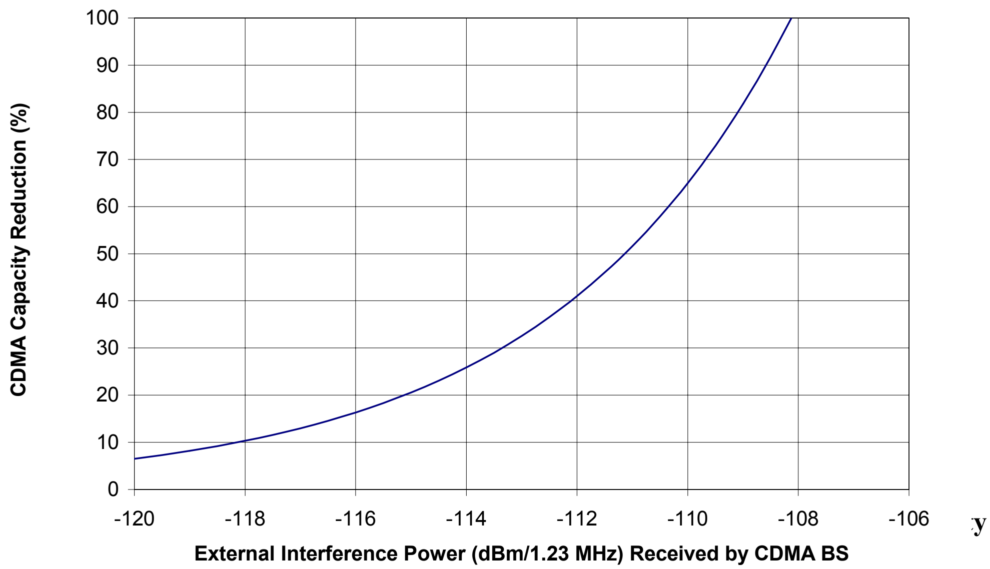
In this section, it is assumed that the cell layout is designed to the maximum propagation loss dictated by the reverse link budget and the service objective is to maintain the coverage. In the presence of external interference from non-CDMA systems, the CDMA BS receiver noise floor will be raised and therefore the reverse link capacity will be reduced. It is shown in A.2 that when the receiver sensitivity and cell coverage remain the same and the cell layout is designed to the maximum propagation loss dictated by the reverse link budget, the CDMA reverse link capacity reduction ratio (R_{cap}) due to external interference can be determined by:

$$R_{cap} = 1 - \frac{N_{w/\,ext}}{N_{w/o\ ext}} = \left(\frac{I_{ext} + FN_o W}{FN_o W} - 1 \right)\left(\frac{1}{\rho} - 1 \right) \tag{3}$$

where $N_{w/\ ext}$ denotes the CDMA capacity with external interference, $N_{w/o\ ext}$ the CDMA capacity without external interference and ρ denotes the CDMA reverse link loading factor. The above equation indicates that the penalty in CDMA reverse link capacity depends on the CDMA BS loading factor and the receiver noise rise caused by external interference.

As an example, we consider IS-95 EVRC. The typical reverse link budget for the IS-95 EVRC with mobility and voice applications, considers a 3.5 dB CDMA BS receiver interference margin (i.e., the noise rise due to other user interference), which corresponds to a 55% loading. Figure 2 shows the relationship between the IS-95 EVRC reverse link capacity loss and the average external interference power when the CDMA cell coverage remains constant. It is observed that an external interference power of –109 dBm/1.23 MHz will cause about 3 dB noise rise and 82% capacity loss. As the external interference power is -120 dBm causing a 0.3 dB noise rise, then the cell capacity reduction becomes about 6%. Service providers can determine a tolerable reverse link external interference power level based on the elected acceptable capacity reduction when performing the network deployment study.

Note that Figure 2 should be viewed as example only and not universally applied to all products and scenarios, since the result will vary with noise figure and receiver sensitivities. For example, the numerical values cannot be applied directly to 3G scenarios, which typically employ a higher (~72%) pole loading.



4. Summary

The presence of reverse link external interference will negatively impact the capacity and coverage of CDMA systems. The impact of external interference can be viewed as degrading capacity while maintaining coverage; alternatively, it can be shown that the cell footprint can be maintained if capacity is degraded.

The computed capacity and coverage degradation may be used to assess the impact of external interference that develops *after* deployment; i.e., new interference that develops relative to the baseline condition of the spectrum. Alternatively, the computed capacity and coverage degradation can be used in pre-deployment design planning to compensate for noisy spectrum if clearance is not practical. For example, closely spaced cells can yield full capacity since a coverage penalty can be tolerated. This strategy is generally considered undesirable since it implies that scarce, expensive radio spectrum is not being fully utilized; however, it may be tolerable in areas where cells must be closely spaced regardless of interference conditions in order to address capacity demands. However, for scenarios such as in-door applications, coverage margin may not exist; any interference levels can effectively reduce system performance.

In all cases, the degradation of performance in the presence of external interference can be significant. Accordingly, it is critical that spectrum be completely cleared in order to fully realize CDMA performance.